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The objective of this effort was to evaluate light obscuration particle counters on U.S. Army tactical fueling equipment to determine if fueling systems and operations would cause particle counters to displaying erroneous results such as when air bubbles are present in the fuel stream.

15. SUBJECT TERMS
Fuel, JP-8, Automatic Particle Counter, cleanliness, free water, Diesel

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-Technical Report-

Evaluation of Particle Counter Technology for Detection of Fuel Contamination Detection utilizing Advanced Aviation Forward Area Refueling System

Joel Schmitigal

January 2014

U.S. Army Tank Automotive Research,
Development, and Engineering Center
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U.S. Army Tank Automotive Research Development and Engineering Center

Warren, Michigan 48397-5000

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Joel Schmitigal
Force Projection Technology

Approved for public release; distribution unlimited

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1. **Introduction**

Fuel quality assurance is accomplished by conducting periodic fuel sampling for the condition monitoring of aviation fuel by detecting, measuring, and reporting the levels of contaminants in the fuel. The currently accepted methods for measuring particulate and free water contamination of fuel supplies include:

- ASTM D2276 - Standard Test Method for Particulate Contaminant in Aviation Fuel by Line Sampling
- ASTM D3240 – Standard Test Method for Undissolved Water in Aviation Turbine Fuels
- ASTM D4176 – Standard Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures)

The current methods have several drawbacks including operator subjectivity, lack of detailed analysis, limitations in providing reliable data, and the turn-around time needed to get the test results.

The U.S. Army maintains the mission of providing quality fuel to all U.S. and Allied troops in tactical environments. Presently, requirements as outlined require a dedicated group of specifically trained fuels personnel to perform several tests per day per installation, looking for traces of sediment and water in the fuel (1)(2)(3).

Current standards, such as MIL-STD-3004, Department of Defense Standard Practice for Quality Assurance/Surveillance for Fuels, Lubricants, and Related Products and Field Manual No. 10-67-2, Department of the Army Manual for Petroleum Laboratory Testing and Operations, specifies limits for free water and particulate matter in aviation fuels. Specifically, free water contamination in jet fuel cannot exceed 10 parts per million (2) and particulate matter contamination cannot exceed 2.0 mg/L for Intra-Governmental transfer receipts and 1.0 mg/L on issue to aircraft, or up to 10 mg/L for product used as a diesel product for ground use (1). Free water contamination (droplets) may appear as fine droplets or slugs of water in the fuel systems. The particulate matter found in field fuel systems varies in shape and is commonly found in the 5 to 40 micron size range. Common particulate matter includes silica, rust, metal shavings, fibrous materials, coatings material including paint, elastomeric materials, hydrocarbon/oxidation materials, and any other solid matter. At a minimum free water and particulate by color (as specified in the appendix of ASTM D2276) are checked daily, while filter effectiveness is checked every 30 days by gravimetric analysis (ASTM D2276).

The U.S. Army Tank Automotive Research Development and Engineering Center **(**TARDEC) and U. S. Army Aviation and Missile Research Development and Engineering Center **(**AMRDEC**)** jointly sponsored a Small Business Innovative Research (SBIR) effort in 2011 awarding a Phase I SBIR contract to Progeny System Corporation under contract W911W6-11-C-0019 to combat contaminated fueling instanced indentified by the Army(4). The Progeny System approach was to utilize ultrasound to independently detect particulate and free water contamination(5; 6).

The use of particle counting and automatic particle counters is prevalent in the hydraulics/hydraulic fluid industry. The International Organization for Standardization (ISO) has published several methods and test procedures for the calibration and use of automatic particle counters. The transition of this technology to the fuel industry is relatively new and several organizations (military and commercial) have conducted testing to ensure the transition from the hydraulic fluid market to fuels is viable.

In recent years, the United Kingdom (UK) based, Energy Institute (EI) published standards relating to fuel quality measurement using sensors. The first edition of EI 1570 Handbook on electronic sensors for the detection of particulate and/or free water during aircraft refueling was published in August 2012, and the second edition of EI 1598 Design, functional requirements and laboratory testing protocols for electronic sensors to monitor free water and/or particulate matter in aviation fuel was published in February 2012. In addition to the handbooks, the EI has also developed three (3) standard test procedures and methods for evaluating the particulate matter of fuels using electronic sensors; IP 564, IP 565, and IP 577.

- IP 564 – Determination of the level of cleanliness of aviation turbine fuel – Laboratory automatic particle counter method
- IP 565 – Determination of the level of cleanliness of aviation turbine fuel – Portable automatic particle counter method
- IP 577 – Determination of the level of cleanliness of aviation turbine fuel – Automatic particle counter method using light extinction

Military aviation fuels meeting the requirements of DEF STAN 91-91 (UK) (7) and MIL-DTL-83133 (US) (8) both include a report only requirement for particle counting. Particulate contaminate limits using particle counters are being developed as test programs and field demonstrations are in progress.

The U.S. Army and U.S. Navy have conducted laboratory evaluations of particle counter technologies for fuel contamination monitoring. The particle counters tested were unable to adequately distinguish between free water and sediment contamination. Conclusions from the laboratory evaluation indicated that particle counters cannot replace current technology where quantification of both free water and sediment contamination is required. However, this technology showed significant promise for monitoring overall fuel quality. To simplify the reporting of particle counter data, the International Organization for Standardization created Cleanliness code 4406:1999 (9). Several interested parties, both commercial and military, have proposed limits based on light obscuration particle counting technologies based on ISO 4406, provided in Table 1 and references (10)(11)(12)(13)(14)(15)(16)(17). As a result of the laboratory testing conducted, the U.S. Army has proposed a working cleanliness limit (based on ISO 4406) of 19/17/14/13 utilizing the 4µm (c)/ 6µm (c)/ 14µm (c)/ 30µm (c) size channels (12). The U.S. Army has included the 30µm size to detect free water in the fuel.

	Receipt	Vehicle Fuel Tank	Fuel Injector
Aviation Fuel			
DEF (AUST) 5695B		18/16/13	
Parker	18/16/13	14/10/7	
Pamas/Parker/Particle Solutions	19/17/12		
U.S. Army	19/17/14/13*		
Diesel Fuel			
World Wide Fuel Charter 4th		18/16/13	
DEF (AUST) 5695B		18/16/13	
Bosch/Cummins		18/16/13	
Donaldson	22/21/18	14/13/11	12/9/6
Pall	17/15/12	15/14/11	12/9/6 11/8/7

Table 1. Proposed Particle Counter Limits
***addition of 30 micron channel proposed by U.S. Army for detection of free water.**

2. **Project Background**

In 2013 Defense Logistics Agency – Energy funded a Tri-Service Field Evaluation of Automatic Particle Counters. Each Service chose two locations to conduct testing. The U.S. Army chose to conduct testing at Campbell Army Airfield at Fort Campbell, KY(18), and three Army Heliports (AHP) at Fort Rucker, AL(19).

The test results at Fort Rucker clearly demonstrated the on-line particle counters susceptibility to providing erroneous results in the presence of air bubbles in the fuel stream. In addition to the light obscuration particle counters displaying these erroneous results when air bubbles were known to be in the fuel stream during fuel receipt operations the test results at Monielli Stagefield Army Heliport’s Pad 11, which is at the furthest point away from the bulk fuel storage facility at Molinelli Stagefield AHP fed by a 1/3 mile underground fuel line. The data seen at Monielli Stagefield Army Heliport had spikes corresponding to the fuel pump at the airfield automatically shutting off every 10 minutes and were theorized as being caused due to a “water hammer” effect in the fuel system that shook water free from pockets within the fuel system piping(19). While AMRDEC was conducting Alcohol to Jet (ATJ) fuel flight testing at Redstone Test Center, TARDEC was afforded the opportunity to evaluate light obscuration particle counters on the Advanced Aviation Forward Area Refueling System (AAFARS) being utilized for this testing.

3. **Approach**

The AAFARS utilized for the ATJ testing at Redstone Test Center was fed fuel from a tanker truck shown in Figure 1. A fuel sample port, was inserted into the recirculation loop downstream of the filter separator to simulate being in line with fueling nozzle.

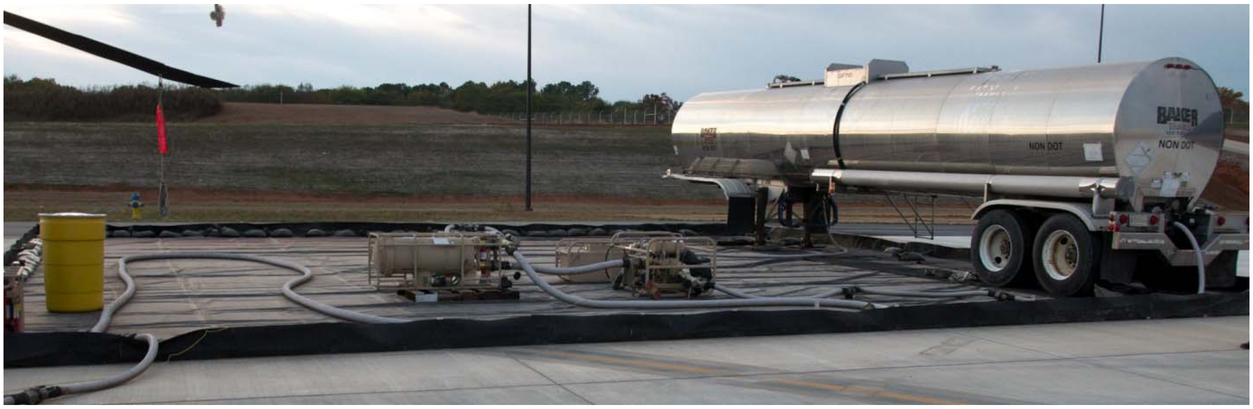

Figure 1. Redstone Test Center Advanced Aviation Forward Area Refueling System (AAFARS) setup for Alcohol to Jet (ATJ) fuel flight testing.

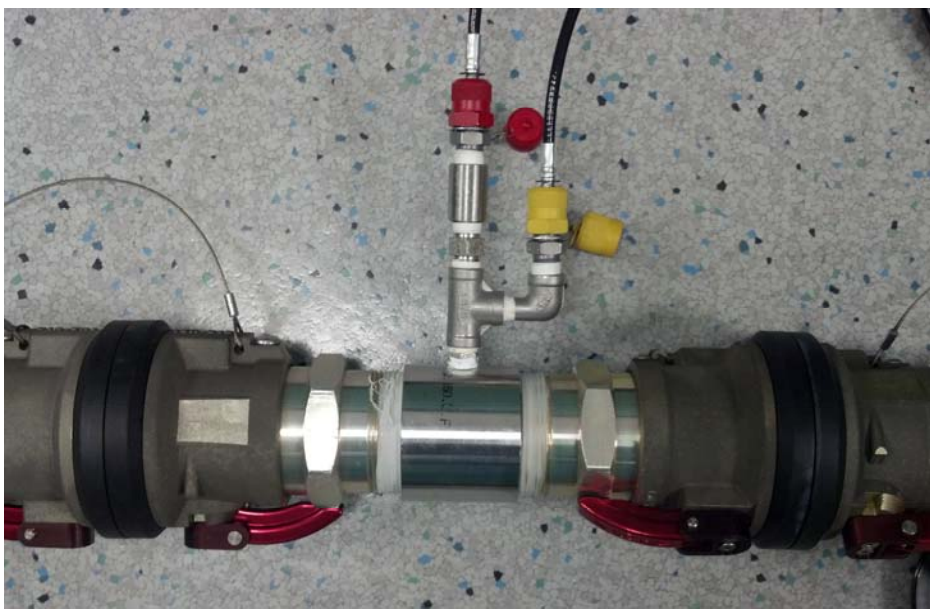

Figure 2. AAFARS fuel sampling port for use with light obscuration particle counters.

The AAFARS was run under the following conditions to simulate aircraft refueling operations, while particle counts where obtained utilizing a Parker iOS particle counter:

- Recirculation – fuel was pumped from the tank, through the filter separator and back into the fuel tank.

- Aircraft fueling simulation – a valve downstream of the filter separator and particle counter was rapidly opened and closed to create a water hammer effect on the hose line and filter separator.
- Recirculation – fuel was again pumped from the tank, through the filter separator and back into the fuel tank.
- Air in filter housing – two gallons of fuel was removed from the filter separator vessel, creating a pocket of air in the vessel. The particle counters were started and then the AAFARS fuel pump was initiated pushing the air from the filter vessel back to the fuel tank. This test was to simulate failing to purge the filter vessel of air following filter replacement of water bottom removal.
- Recirculation – Air was purged from the filter separator vessel and fuel was again pumped from the tank, through the filter separator and back into the fuel tank.

The instrumentation utilized for the evaluation was an online instrument Parker icountOS, Figure 3, the same instrumentation utilized in the Fort Campbell and Fort Rucker evaluations. The Parker icountOS instrument contains the same internal optics as the Parker ACM 20 specified in IP 564, Determination of the level of cleanliness of aviation turbine fuel - Laboratory automatic particle counter method, is calibrated to ISO 11171, Hydraulic fluid power - Calibration of automatic particle counters for liquids, and reports ISO 4406, Hydraulic fluid power - Fluids - Method for coding the level of contamination by solid particles, codes directly. The iOS instruments are capable of pumping the fuel back into the supply lines; thus creating no waste fuel. Ideally, these instruments can be left in the field to monitor and collect data for fuel transfers. For this demonstration the IOS units were configured to pull fuel samples when manually initiated by the operators for each data set.

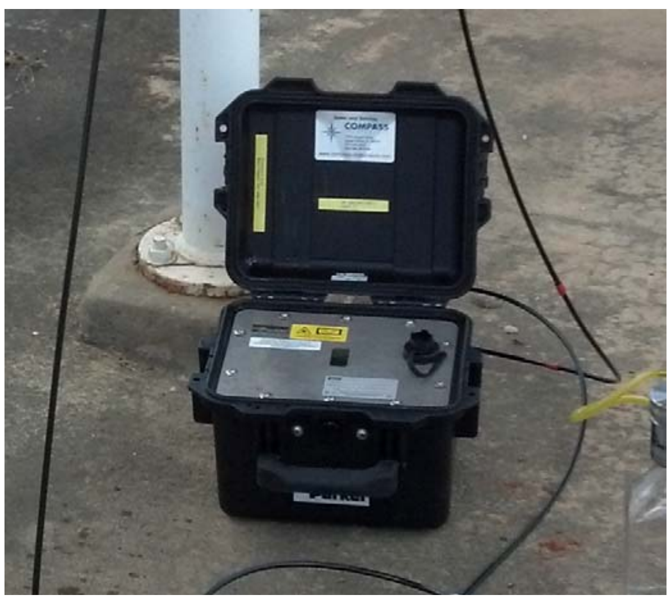

Figure 3. Parker IcountOS light obscuration particle counters utilized for evaluation.

4. **Analysis**

The data obtained during testing with the Advanced Aviation Forward Area Refueling System (AAFARS) at Redstone Test Center was consistent with the Army's previous experiments utilizing light obscuration particle counters and can be found in Table 2.

condition	instrument	Date\Time	4u	6u	14u	30u
recirculation	4	09/01/2014 10:34.03	20	18	16	14
recirculation	4	09/01/2014 10:37.41	16	14	11	9
recirculation	4	09/01/2014 10:40.04	16	14	11	7
recirculation	4	09/01/2014 10:42.25	15	14	9	6
recirculation	4	09/01/2014 10:45.05	14	13	9	6
recirculation	4	09/01/2014 10:47.09	14	12	9	6
recirculation	4	09/01/2014 10:49.47	13	12	9	5
water hammer	4	09/01/2014 10:51.55	15	13	10	7
water hammer	4	09/01/2014 10:53.59	15	14	11	9
water hammer	4	09/01/2014 10:56.23	15	13	10	8
recirculation	4	09/01/2014 10:58.38	14	13	10	7
recirculation	4	09/01/2014 11:00.44	13	12	9	7
air in filter housing	7	09/01/2014 11:19.42	16	14	12	10
air in filter housing	7	09/01/2014 11:21.52	15	13	10	7
water hammer	7	09/01/2014 11:24.30	17	16	12	10
water hammer	7	09/01/2014 11:26.56	15	14	11	8
recirculation	7	09/01/2014 11:29.38	14	13	10	6
recirculation	7	09/01/2014 11:31.40	13	12	9	3

Table 2. Redstone Test Center Advanced Aviation Forward Area Refueling System (AAFARS) particle count data.

Following startup of the AAFARS pump the particle counter was started and took its first reading 20/18/16/14, falling outside of the Army's proposed particle counter limits due to air in the particle counter sampling line. The following six samples in recirculation mode saw the particle counts drop below the proposed 19/17/14/13 limits and continue to drop as cleaner fuel was pumped through the filter separator. This was also seen in the storage tanks at Fort Campbell and Fort Rucker, and is theorized to happen due to the stratification of particulates caused by gravity settling in the storage tank over time causes the dirtiest fuel in the tank to be at the bottom and thus be pumped out first when sampling from the bottom of a storage tank.

To simulate the opening and closing of a fueling nozzle a valve downstream of the pump, filter separator, and particle counter was rapidly opened and closed causing a water hammer effect on the AAFARS. Three particle counter samples were recorded under these conditions with the initial reading being 15/13/10/7, followed by 15/14/11/9, and 15/13/10/8. These readings were higher than the recirculation reading taken just prior, potentially due to the pressure shock on the filter elements shaking dirt off the element and into the fuel stream.

Ceasing the fueling simulation and the water hammer effect saw the particle counts rapidly drop back down to the 14/13/10/7 and 13/12/9/7 levels seen immediately prior to the fueling simulation.

To simulate failing to purge the filter vessel of air following filter replacement of water bottom removal two gallons of fuel was removed from the filter separator vessel, creating a pocket of air in the vessel. The particle counters were started and then the AAFARS fuel pump was initiated pushing the air from the filter vessel back to the fuel tank. The particle count reading saw a slight increase across all four channels giving a 16/14/12/10, and a 15/13/10/7, the second reading was lower as the fuel flow removed the air from the filter vessel. Both readings below the Army's proposed 19/17/14/13 ISO code limits. These reading elevations were distributed across all the read channels, unlike the air bubble data seen at Fort Rucker which saw larger jumps in the 14µm and 30µm channel jump up to 16 and 15 respectively, but very similar in particle counts and size distribution of the particle count readings seen at Fort Rucker's Molinelli Stagefield AHP which saw spikes of 12/11/9/7, 15/14/12/9, and 14/13/11/8, with a baseline ranging around 7/5/3/0.

After purging the filter vessel of air, of which there appeared to be none, the fueling simulation was resumed by opening and closing a valve downstream of the pump, filter separator, and particle counter causing a water hammer effect on the AAFARS. This caused the particle count readings to jump above the readings seen when the air was in the system with recorded readings of 17/16/12/10 and 15/14/11/8, both acceptable values. The increased was again perceived as being caused by the pressure shock on the filter elements pushing dirt off/through the element and into the fuel stream.

To conclude the testing the AAFARS was returned to recirculation mode and two final particle count readings were taken with the 14/13/10/6 and 13/12/9/3 readings falling closely in line with the previous recirculation readings.

5. **Conclusion**

The test results indicate that on-line particle counters, while susceptible to the presence of air found in fueling systems, appear to be compatible to the Army's tactical fueling systems. It should be noted the ATJ testing utilized a commercial fuel tanker to house the bulk petroleum product and not the fuel drums or collapsible fuel storage bags/tanks which may induce more air into the fuel stream than the commercial fuel tanks. The Army's tactical fuel storage drums and collapsible fuel storage bags/tanks are more likely to cause air entrainment in the fueling stream due to the location of fill or discharge port than is seen in commercial fuel tanks with bottom discharge points.

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List of Symbols, Abbreviations, and Acronyms

μm	Micrometer
AAFARS	Advanced Aviation Forward Area Refueling System
AHP	Army Heliport
AL	Alabama
ASTM	ASTM International
ATJ	Alcohol to Jet
AUST	Australia
DEF	Defence/Defense
DTL	Detail
EI	Energy Institute
iOS	icountOS
ISO	International Organization for Standardization
KY	Kentucky
mg/L	Milligrams per Liter
MIL	Military
STAN	Standard
STD	Standard
TARDEC	Tank Automotive Research Development and Engineering Center
U.S.	United States
UK	United Kingdom